Progress on utilizing space borne high resolution thermal radiometer in water resources research and management

A brief note summarizing some Dutch and other European experience, 24 March 2003
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General

The Enhanced Thematic Mapper and ASTER are currently the only two operational space borne high resolution thermal infrared radiometers. This note is prepared by a group of European scientists who wish to share their experience in the utilization of these specific data in a larger group, and who are concerned that a discontinuation of ETM-TIR will have adverse effects on hydrologic studies, the management of water resources, and future food production. The aim of this note is to contribute to the current concern that the USA may suspend the high resolution TIR mission.

The common dominator of this Wageningen-related group is the interest in surface energy balances. The surface energy balance provides through the latent heat flux a direct assessment of the consumptive use of water resources. Related to the latent heat flux is the availability of water to vegetation, i.e. the water that is stored in the upper soil layers and extracted by roots. There is a strong desire from multiple directions to quantify and manage soil moisture (for irrigation, water logging, water table control, recharge, runoff etc.) and vegetation water stress is an important input for quantifying soil moisture. Furthermore, the latent heat flux is coupled to transpiration of vegetation, and through that to carbon assimilation and production of crops, forests and natural ecosystems. The health of ecosystems depend very much on the intake of carbon, which ultimately affects the atmospheric CO_2 concentration. These spatially variable processes can be quantified from TIR data.

Academic Research Developments

In Wageningen – The Netherlands – research groups are involved in the development of energy balance models that depend on thermal infrared radiances (e.g. the SEBI, SEBAL, SEBS, SHEBA). These energy balance models differ in the level of physics, the type of applications and number of studies where they have been used. In addition to a wide assortment of applications, the energy balance model development has resulted in a series of Ph.D. theses (see table below) that provide an indication of the substantial activity using TIR.

Table: Ph.D. theses related the thermal infrared satellite data from Wageningen University

Year	Promovendus	Title
1984	Menenti	Physical aspects and determination of evaporation from deserts
1986	Ten Berghe	Heat and water transfer at the bare soil surface
1991	van Loon	Heat and mass transfer in frozen porous media
1995	van den Hurk	Sparse canopy parameterization for meteorological models
1995	Verhoef	Surface energy balance of shrub vegetation in the sahel
1995	Bastiaanssen	Regionalization of surface flux densities and moisture indicators in composite terrain
2000	Pelgrum	Spatial aggregation of land surface characteristics
2000	Farah	Estimation of regional evaporation under different weather conditions from satellite and meteorological data
2002	Ahmad	Estimation of net groundwater use in irrigated river basins using geo-information techniques
2003	Li Jia	Title unknown
2003	Meijninger	Scintillometers and TIR remote sensing for all weather ET estimates

The advantage of using high resolution TIR data is that energy balance behavior of individual land use classes, crop types and plot boundaries can be distinguished in tandem with shortwave spectral information. This is of paramount importance in the study of relationships between ecosystems and water consumption. Some examples of application include assessing boundaries between areas with water rights and without them, studies of the effects of rising water tables, evaluation of equity of water allocation and sharing, and impacts of large scale water consumption on endangered species. The application of crop yield studies require at least a homogeneous pixel with a single crop type, and accurate yield production and consumption of water can only be feasibly detected with TIR data from Landsat and ASTER. Although MODIS, AATSR, NOAA and MSG provide very useful opportunities to monitor the energy balance at meso scale, none of these satellites provide crop and field specific data. Despite that this meso scale category of TIR data is suitable for climate and river basin studies, the data are less useful for irrigation, forestry and agricultural applications.

From research to application

Approximately 350 high resolution TIR images have been used for surface energy balance modelling among the 4 entities preparing this note. The table underneath provides a summary of surface energy balance studies that have been conducted in some very critical areas of the globe. The worldwide coverage in research and application studies reveals a broad international and common interest in energy balance products. This goes far beyond the point that an interesting case is tested - in a specific area - for a particular purpose (as often done by research institutes). There is a generic message of proven wide interest and application success.

More than half of the noted studies have been carried out during the last 5 years, which pinpoints a rapidly growing interest and a proper short-term marketing perspective. This indispensably is related to the international concern of managing scarce water resources better and the paradigm shift to "water is every body's business"[1].

Although TIR images are still used for critical research and development, there is solid evidence that the number of application studies are rapidly overtaking that of research (see Figure). This demonstrates that after a long period of thorough academic studies, the era of "energy balance engineering" has begun. Application studies are typically studies executed for end-users who cover all costs without subsidy. The project objectives are related to water resources, not to the remote sensing data acquired and the development and testing of remote sensing algorithms. End-users are Water Resources Departments, Water Boards and Irrigation Departments in countries that can afford the costs of hiring commercial remote sensing consultants.

In developing countries, the costs related to TIR remote sensing studies are covered by donor agencies such as the World Bank, Asian Development Bank etc. These donors have a keen interest in investigating the impact of international water projects and the evaluation of meeting improved water management objectives[2].

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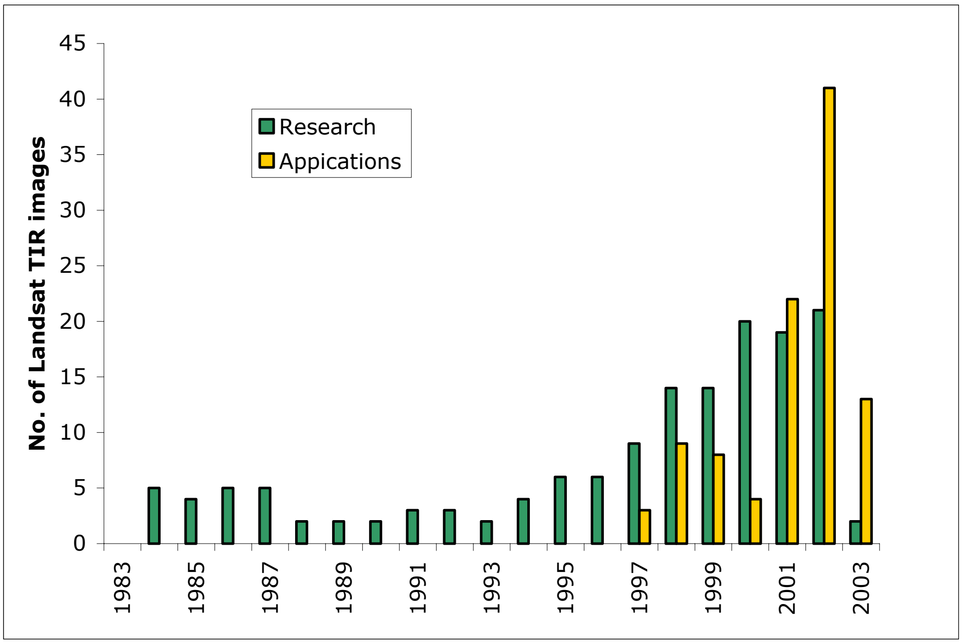
[1] Slogan of the 2nd World Water Forum

[2] The group of donors to developing countries (Banks, USAID, GTZ etc.) need to be involved in the dialogue on user request for high resolution TIR satellites

Table: High resolution TIR imagery used in hydrologic studies during 1992-2002 by the 4 entities signing this note. The number of Landsat images are specified between brackets

Continent	Country	Research	Application
Europe	The Netherlands	√ (12)	√ (10)
	Spain	√ (7)	√ (5)
	Portugal		√ (3)
	Italy	√ (3)	
Asia	Turkey	√ (2)	√ (4)
	Iran	√ (10)	
	Yemen		√ (5)
	Uzbekistan		√ (2)
	Pakistan	√ (5)	√ (20)
	India	√ (25)	
	Sri Lanka	√ (2)	√ (3)
	China	√ (5)	√ (10)
Africa	Egypt	√ (10)	√ (5)
	Lybia	√ (5)	
	Sudan	√ (4)	
	Niger	√ (3)	
	Kenya	√ (2)	
	Zimbabwe	√ (1)	
	Botswana	√ (10)	
	South Africa		√ (1)
Americas	Idaho	√ (20)	√ (110)
	New Mexico	√ (10)	
	Florida		√ (3)
	Washington		√ (1)
	Mexico		√ (8)
	Panama		√ (1)
	Brazil		√ (2)
	Argentina	√ (10)	
TOTAL		± 150	± 200



Commercial providers of thermal infrared services can play a key-role in bridging science to TIR-implementations. The existence of an outreach mechanism is critical for enhancing the utilization of high-resolution TIR images. The graph shows that after 2000, applications have exceeded research volume by the undersigned group. This is at least the situation for one type of application (water resources) by one particular community

(Wageningen related). It would be interesting to derive similar overviews by other user communities.

It took about 20 years to understand the value of the TIR band for hydrologic and water management studies. The period between 1984 and say 1996 was mainly necessary to understand the signal and develop proper algorithms (which needs to continue to remain up to date). During the last 3 years, the number of applications with clients paying for TIR data has increased steeply. The number of TIR images used for 2003 are applicable to the first quarter of the year, and if this trend continues, the number of 2003 images will exceed the 2002 level.

Future

High resolution TIR data, in association with high resolution short-wave spectral data, should be frequently available; ideally on a week-to-week basis for monitoring water depletion, crop growth and carbon assimilation. The growth period of short duration crops such as rice (120 days) demand weekly images. Since many countries at the higher latitudes and in the tropics are frequently cloud covered, a time interval between successive TIR satellite overpasses of a few days is necessary to get weekly or two-weekly cloud free images. In a country like The Netherlands, on average only 3 cloud free Landsat scenes in the summer between May and August with a 16 day revisit period are obtained. This is insufficient for many applications. The current 16 days interval of Landsat and the irregular activity of acquiring ASTER data is not sufficient for many potential applications of energy balance work and quantification of water consumption. However, the Landsat ETM images, complemented by TM images from Landsat 5, have been extremely valuable for many of our operational applications. In absence of a similar TIR replacement, it is imperative that these operations continue.

It should be noted that some of the more currently widely used energy balance applications, do not require correction of TIR for atmospheric effects, as these energy balances are internally calibrated around any error in the TIR (the latter hold specifically true for SEBAL). What is important is consistency of TIR within single images and time-correspondence with short-wave information. This is currently available with ETM and ASTER.

Further to the ASTER type of sensor specifications, it is preferable to have:

1. Multiple observation angles to derive the surface temperatures of plant leaves and soil separately, which is crucial for partitioning evapotranspiration into transpiration and evaporation (same concept as AATSR). This partitioning allows for the separation between beneficial and non-beneficial water consumption.
2. Multiple TIR channels to apply atmospheric correction schemes (needed for some energy balance applications, but not all) and to aid the emissivity-temperature separation from inversion of the Planck equation.
3. A TIR pixel size of 30 to 90 m to provide adequate definition between adjacent fields and crop types.
4. An overpass time later than 11.00 A.M. local time to provide for the generation of sufficient radiation to obtain more contrasting surface temperatures and temporally conserved energy balance fractions (the period between noon and 2.00 PM is preferred).
5. A constellation of TIR satellites to reduce the large time gap between successive cloud free images.
6. Sufficient corresponding short-wave information to provide for complementary vegetation indexing (surface albedo, fractional vegetation cover and leaf area index) and full energy balance based on broad-band reflectance.
7. Large path width (similar to ETM) for efficiency in processing for large areas

The fraction of the world population having hunger and having less water available than required for normal living and food production (i.e. > 1700 m^3/yr/cap) is growing. Nearly a third of the world's population live in regions that will experience severe water scarcity in 2025. This team is convinced that TIR remote sensing can quantify hydrologic processes, key water management issues and food production status. There is a pressing need for sustaining TIR observations both in and beyond Landsat and ASTER. This need is no longer defined only by the scientific community, but should appear quickly on the agenda of international organizations and donor agencies that are concerned with water scarcity and the degradation of livelihoods in rural societies.

Quantitative information on the actual processes occurring in the soil-water-plant-atmosphere system are scant. TIR remote sensing can play a vital role in providing policy makers and managers reliable and up-to-date information on which they can base their critical decisions regarding food supply, water consumption, and resource management needs.

For

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